REAL TIME IMPLEMENTATION OF NONLINEAR AUTOREGRESSIVE WITH EXOGENOUS INPUT MODEL PREDICTIVE CONTROL FOR BATCH ENZYMATIC ESTERIFICATION PROCESS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS

$\dot{Q}_J$	Heat flow through the jacket
ΔH_{rxn}	Heat of reaction
A_{iB}	Pre-exponential factors for inhibition of lauric acid
A_{iQ}	Pre-exponential factors for inhibition of water
A_{mA}	Pre-exponential factors for Citronellol
A_{mB}	Pre-exponential factors for lauric acid
A_r	Heat exchange area
Cp_A	Specific heats of Citronellol
Cp_B	Specific heats of lauric acid
Cp_P	Specific heats of Citronellyl laurate
Cp_Q	Specific heats of water
Cp_j	Specific heat of water in the jacket
E^*, EA, EAB, EPQ, EQ	Transitory enzyme complex
E_{iB}	Activation energy for inhibition of lauric acid
E_{iQ}	Activation energy for inhibition of water
E_{mA}	Activation energy for Citronellol
E_{mB}	Activation energy for lauric acid
$F_{air,out}$	Outlet air flowrate
F_{air}	Inlet air flowrate
F_j	Inlet jacket flowrate
K_{iB}	Inhibition constant for lauric acid
K_{iQ}	Inhibition constant for water

K_{mA}	Michaelis constant for citronellol
K_{mB}	Michaelis constant for lauric acid
M_W	molecular weight of water
N_e	Number of equations
N_f	Degree of freedom
N_v	Number of dependent variables
P_W^o	Partial pressure of pure water
$P_{w,in}$	Partial pressure of water in the inlet
$P_{w,out}$	Partial pressure of water in the outlet
$Q_{air,out}$	Amount of water vapour leaving reactor
Q_{air}	Amount of water vapour entering reactor
Q_{tot}	Total amount of water
$T_{air,in}$	Temperature of air in the inlet
$T_{air,out}$	Temperature of air in the outlet
T_j	Jacket temperature
T_{ji}	Jacket temperature inlet
T_r	Reactor temperature
T_s	Sampling period
V_j	Volume of the jacket
V_{max}	Maximum rate of reaction
$a_{w,in}$	Inlet water activity
a_w	Water activity in the reaction
$k_{-1}, k_{-2}, k_{-3}, k_{-4}, k_{-p}$	Reverse rate constant
k_1, k_2, k_3, k_4, k_p	Forward rate constant

n_u	Input order
n_y	Output order
r_k	Weighting factor for input
w_k	Weighting factor for output
$\tilde{y}$	Output response from FOPTD model
$\bar{y}$	Mean of the output response
y_1	Output response for reactor temperature
y_2	Output response for water activity
y_m	Model output response
y_{sp}	Output setpoint
γ_w	Activity coefficient of water
$\theta_{n_u n_y}$	Empirical model cluster coefficient
ρ_j	Density of water in the jacket
ϕ_N^u	Nonlinearity measure
M	Moving horizon
P	Prediction horizon
R	Gas constant
A	Concentration of Citronellol
B	Concentration of lauric Acid
E	Candida rugosa lipase
G	Linear model
K	Process gain for FOPTD
N	Nonlinear model
P	Concentration of Citronellyl laurate

Q	Concentration of water from reaction
U	Heat exchange coefficient
V	Volume of the reactor
a	Coefficients for originating exogenous terms
b	Coefficients for autoregressive terms
c	Coefficients for cross terms
e	Process error
i	Time lag for input
j	Time lag for output
t	Time
u	Input response
y	Output response
θ	Time delay
τ	Time constant for FOPTD

LIST OF ABBREVIATIONS

ANN	Artificial Neural Networks
ARMAX	Autoregressive Moving Average with Exogenous Input
ARX	Autoregressive with exogenous input
ARX-MPC	Autoregressive with exogenous input- Model Predictive Control
BB	Branch and Bound
DEE	Differential Equation Editor
deWMA-MPC	Double Exponentially Weighted Moving Average Based MPC
DMC	Dynamic Matrix Control
DOF	Degree Of Freedom
EKF	Extended Kalman Filter
FLC	Fuzzy Logic Controller
GA	Genetic Algorithm
GC	Gas Chromatograph
GDR-GPC	Generalized Delta Rule algorithm based Generalized Predictive Control
GDR	Generalized Delta Rule
GMC	Generic Model Controller
GUI	Graphical User Interface
HFPC	Hybrid Fuzzy Predictive Control
IAE	Integrated Absolute Error
IMC	Internal Model Control
ISE	Integrated of Squared Error
LMPC	Linear Model Predictive Control

LV-MPC	Latent Variable Model Predictive Control
MHE	Moving Horizon Estimation
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MPC	Model Predictive Control
MSE	Mean Squared Error
NARMAX	Autoregressive Moving Average with Exogenous
NARX	Nonlinear Autoregressive with Exogenous Input
NARX-MPC	Nonlinear Autoregressive with Exogenous Input-Model Predictive Control
NLH-MAC	Nonlinear Hammerstein - Model Algorithmic Control
NLP	Nonlinear Programming
NMPC	Nonlinear Model based Predictive Control
NN-MPC	Artificial Neural Network-Based MPC
PBE	Population Balance Equation
PCA	Principle Component Analysis
PI	Proportional-Integral Control
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Control
PLS	Partial Least Squares
PRBS	Pseudo Random Binary Sequence
QP	Quadratic Programming
R^2	Correlation coefficient
RB	Radial Basis
RLSE	Recursive Least Squares Estimation

R2R	Run-to-Run
RTWT	Real-Time Windows Target
SISO	Single Input Single Output
SQP	Sequential Quadratic Programming
SSE	Sum Squared Error

PELAKSANAAN MASA NYATA UNTUK KAWALAN RAMALAN MODEL AUTO MUNDUR TAK LELURUS DENGAN MASUKAN LUAR UNTUK PROSES PENGESTERAN BERMANGKIN KELOMPOK

ABSTRAK

Proses pengesteran bermangkin lipase merupakan suatu proses penting dalam industri makanan dan farmaseutik. Pencapaian pengeluaran optimum dalam proses pengesteran adalah satu cabaran yang besar disebabkan oleh pelbagai faktor yang mempengaruhi kinetik proses tersebut. MPC direka bentuk dan dilaksanakan dalam kajian ini untuk mengawal suhu dan aktiviti air dalam proses pengesteran bermangkin lipase. Sebelum itu, model kinetik yang mematuhi mekanisma Bi-Bi teratur dibangunkan untuk mengkaji fungsi aktiviti air dan suhu. Parameter kinetik untuk proses ini dianggarkan menggunakan fungsi interp dalam perisian MATLAB®. Kemudian, model prinsip pertama dengan model kinetik dibangunkan dan disahkan dengan data eksperimen. Model prinsip pertama diselesaikan menggunakan tertib ke-empat kaedah Runge-Kutta (ode45) dengan menggunakan gambar rajah blok Editor Persamaan Pembezaan (DEE) yang dibangunkan menggunakan perisian MATLAB®. Model yang dibangunkan menunjukkan keupayaan ramalan yang kuat untuk mewakili proses sebenar. Model prinsip pertama yang disahkan itu kemudiannya digunakan untuk mengkaji kepekaan dan ketaklinearan serta untuk menjana data masukan/keluaran untuk model empirikal. Berdasarkan kajian kepekaan, pembolehubah masukan iaitu kadar aliran jaket, suhu jaket dan kadar aliran udara mempunyai kesan yang bererti terhadap pembolehubah keluaran iaitu suhu reaktor dan aktiviti air. Kajian ketaklinearan menunjukkan

bahawa proses pengesteran bermangkin lipase boleh diklasifikasikan sebagai proses tak linear sederhana. Objektif strategi kawalan MPC ialah untuk mengawal suhu reaktor dan aktiviti air bagi sebuah reaktor pengesteran kelompok. Model empirik yang tertanam dalam MPC, dibangunkan menggunakan model Auto-mundur Lelurus dengan Masukan Luar (ARX) dan model Auto-mundur Tak Lelurus dengan Masukan Luar (NARX) dan masing-masing dikenali sebagai ARX-MPC dan NARX-MPC. Anggaran parameter dan pengesahan model untuk model empirik dijalankan menggunakan peralatan pengenalan sistem anggaran kuasa dua terkecil berulang (RLSE) dalam MATLAB®. Keputusan yang diperoleh menunjukkan bahawa model NARX lebih sepadan dengan data sebenar jika dibandingkan dengan model ARX. Parameter MPC pula ditala untuk menentukan prestasi pengawal terbaik. Kemudian, persembahan pengawal ARX-MPC dan NARX-MPC dengan talaan terbaik dibandingkan dan dinilai dari segi pengesanan titik set dan penolakan gangguan. Keputusan ISE yang dicapai dalam kajian ini menunjukkan bahawa pemasangan NARX-MPC yang dibangunkan untuk sistem kawalan adalah amat memuaskan dan mengungguli pengawal ARX-MPC. Selain itu, pengawal NARX-MPC didapati lebih mantap berbanding ARX-MPC dalam kajian ujian keteguhan. Akhir sekali, pengawal NARX-MPC dipilih dan diuji dalam pelaksanaan masa nyata. Hasil kajian menunjukkan bahawa pengawal NARX-MPC berkesan dalam mengawal suhu dan aktiviti air bagi proses dalam persekitaran masa nyata.